Concentration and rotational temperature of N_2^+ ions in RF plasma jet measured by LIF

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Atmospheric pressure plasma jets (APPJs) ignited in Argon (Ar), Helium (He), and Nitrogen (N_2) are the source of many reactive species (H, O, N, NO, OH, N_2^+, O_2^+, O_2^-, O_3, N_2^*, O_2^*, H_2O_2, NO_2^-, and many others), which play an essential role in plasma chemistry and surface chemistry of many plasma processes [1, 2]. The plasma temperature and concentration of these reactive species in the plasma plume are critical factors that determine the effectiveness of a plasma source for specific uses [3], such as heat-sensitive surface treatment and biomedical applications [4, 5]. The key plasma parameters are controlled by feed gas composition, discharge configuration, and excitation frequency, influencing the plasma's ionization and excitation processes, producing various types of reactive species with different concentrations and temperatures of the plasma plume. This work focuses on the measurement of the concentration of N_2^+ ions and their rotational temperature in the plasma plume by laser-induced fluorescence.

A plasma pencil, a capacitively coupled atmospheric plasma jet driven by radio frequency (RF-13.56 MHz) sinusoidal voltage was ignited in helium, flowing through a silica tube. The APPJ (plasma pencil) is used as the source of N_2^+ ions. The outer and inner diameters of the silica tube are 4.3 mm and 2 mm, respectively. Plasma blows into the ambient atmosphere, where it mixes with the air [6].

The rotational spectrum of N_2^+ ions was obtained by scanning a dye laser across rotational transitions. The measured spectra were fitted to simulated spectra from LIFBASE [7], as shown in Figure 1, and the rotational temperature was calculated from the fitting.

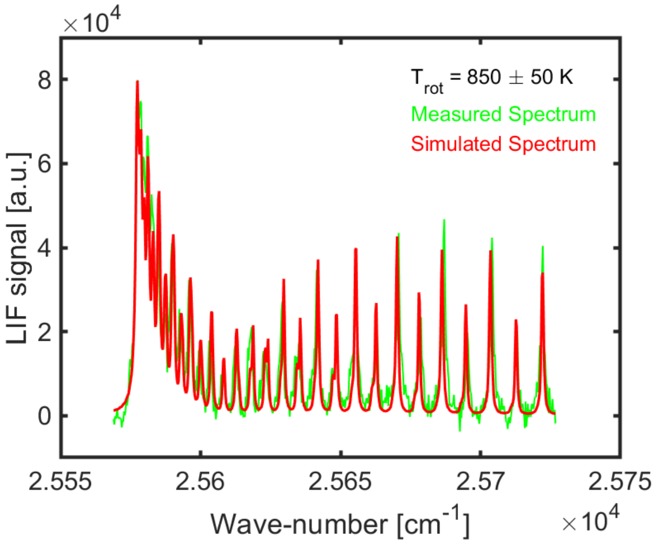

Fig. 1: Fitting of measured and simulated spectra to extract the rotational temperature is shown.

The total density of N_2^+ ions concentration was measured in the effluent of the plasma pencil. The N_2^+ ions concentration dependence on nitrogen gas admixture and RF power was measured as shown in Figure 2 by keeping the He flow rate constant.

The results show that the ions concentration increases up to $1.4 \cdot 10^{17}\,\mathrm{m^{-3}}$ firstly with N_2 flow rate and then decreases for further nitrogen admixture as shown in Figure 2 (left). As the N_2 flow rate increases, more nitrogen molecules are available in the effluent of the plasma pencil, and more collisions between the N_2 molecules with electrons and penning ionization lead to higher nitrogen ionization. So, the density of N_2^+ ions increases initially. However, if we continue increasing the N_2 flow rate, ionization saturation happens, which is caused by several reasons, including the electron energy loss through vibrational and rotational levels of N_2, increase in the collisional quenching rate of helium

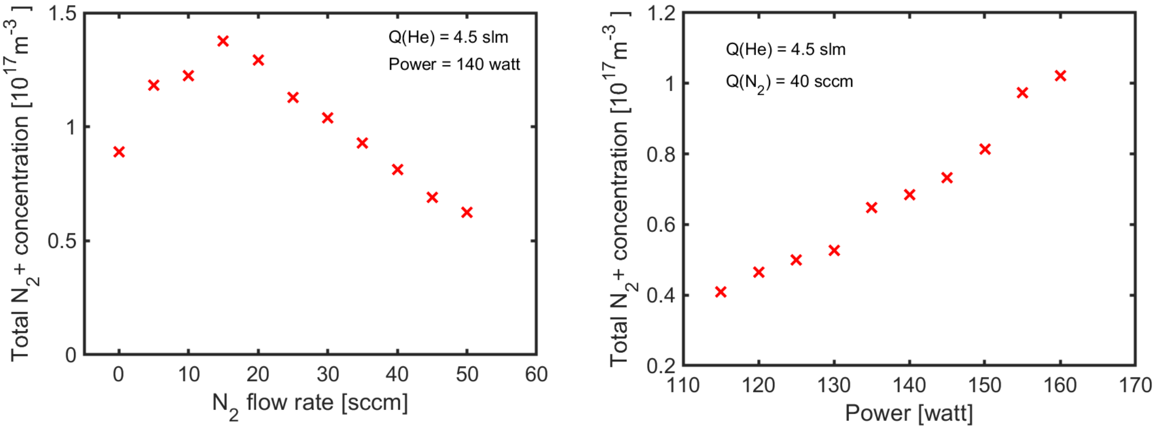

Fig. 2: Dependence of the N_2^+ on the flow rate of N_2 and RF power, keeping the He flow rate constant.

metastable atoms with N_2. Additionally, Jiang Y [8] reported that if N_2 impurity in helium plasma jet is higher than 0.1 % the destruction rates of N_2^+ by the following reactions,

$$N_2^+ + 2\,N_2 \longrightarrow N_4^+ + N_2$$
$$N_2^+ + N_2 + He \longrightarrow N_4^+ + He$$

exceed the production rates of N_2^+ ions occurred due to electron impact ionization and Penning ionization of nitrogen molecules by helium metastables.

The N_2^+ ions concentration increases with the RF power, as shown in Figure 2 (right). As the RF power increases, the overall electron concentration increases, increasing the concentration of high-energetic electrons, so more electrons impact the ionization are the source of N_2^+ ions production.

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